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Mapping polarization fields in $Al_{0.85}In_{0.15}N/AlN/GaN$ heterostructures

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Materials based on $Al_{1-x}In_xN$ offer much potential for the fabrication of high electron mobility transistors (HEMT) because the spontaneous polarization difference between InAlN and GaN should give rise to positive polarization charge at the AlInN/GaN interface [1]. Furthermore, electrons in nearby regions should compensate for this polarization charge, leading to the formation of two-dimensional electron gas (2DEG). AlInN/GaN HEMT heterostructures grown on sapphire substrates have been reported with a 2DEG density of ~$2.6x10^{13}cm^{-2}$ [2]. The position of the 2DEG layer has yet to be determined and structural analysis is lacking. In this study, we have investigated the microstructure and electrostatic potential profiles across $Al_{0.85}In_{0.15}N/AlN/GaN$ HEMT heterostructures. These materials were grown in an AIXTRON 200/4 RF-S metalorganic vapor-phase epitaxy (MOVPE) system on 2-in. *c*-plane sapphire substrates. A JEOL 4000EX was used for microstructural analysis, a JEOL 2010 was used for small-probe microanalysis, and a Philips-FEI CM200 was used for holographic studies.

A cross-sectional bright-field TEM micrograph of the $Al_{0.85}In_{0.15}N/AlN/GaN$ HEMT structure, taken on the $[10\underline{1}0]$ zone axis is shown in Fig. 1a. Well-defined and abrupt $Al_{0.85}In_{0.15}N/AlN$ and AlN/GaN interfaces are observed and the uniform contrast of the AlInN layer indicates that there is no phase separation in this layer. Defect analysis using plan-view imaging (Fig. 1b) showed that the threading dislocation density was ~ $9x10^8cm^{-2}$[3]. Figure 2a shows HAADF STEM image of the HEMT structure, and Fig. 2(b) shows a corresponding EDX line profile. Off-axis electron holography was used to measure the potential profile across the $Al_{0.85}In_{0.15}N/AlN/GaN$ heterostructure. Figures 3(a) and (b) show phase and amplitude images, respectively, from the reconstructed hologram of the $Al_{0.85}In_{0.15}N/AlN/GaN$ HEMT. Profile measurements (Fig. 3c) indicate a polarization-induced electric field of 6.9MV/cm within the AlN layer. A two-dimensional electron gas with a density of ~$2.1x10^{13}cm^{-2}$ was located in the GaN layer about ~0.8nm away from the AlN/GaN interface, in reasonable agreement with simulations [4]. Further studies of AlInN/AlN/GaN heterostructures for AlInN barriers with different thicknesses and different In concentrations are ongoing [5].

References

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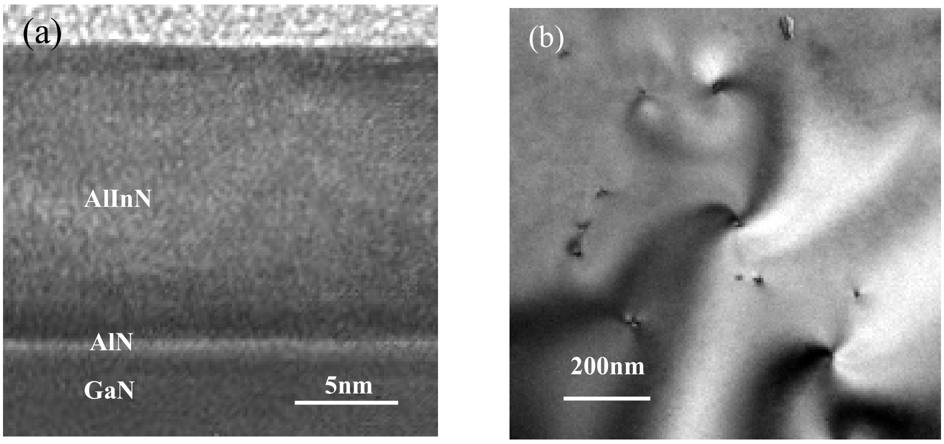

Fig. 1. (a) Bright-field TEM image of the HEMT structure. (b) Plan-view TEM image of the HEMT structure.

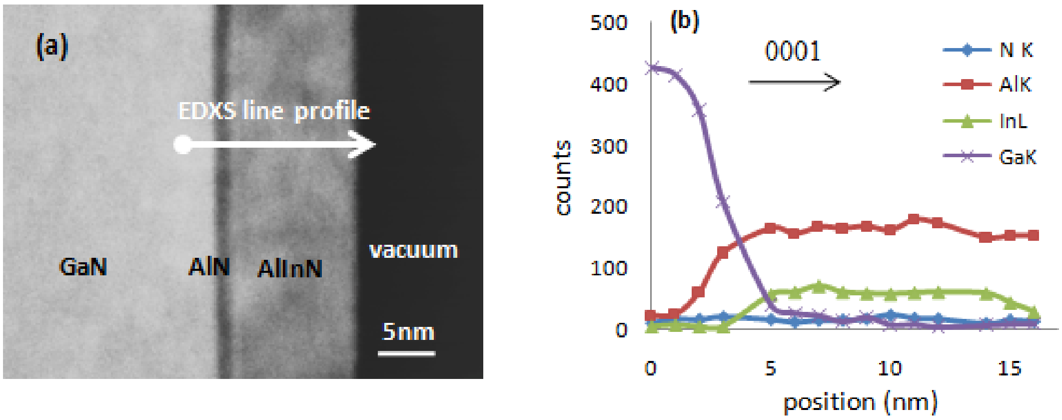

Fig. 2 (a) HAADF STEM image of the HEMT structure; (b) EDXS line profile across the interface from region indicated in (a).

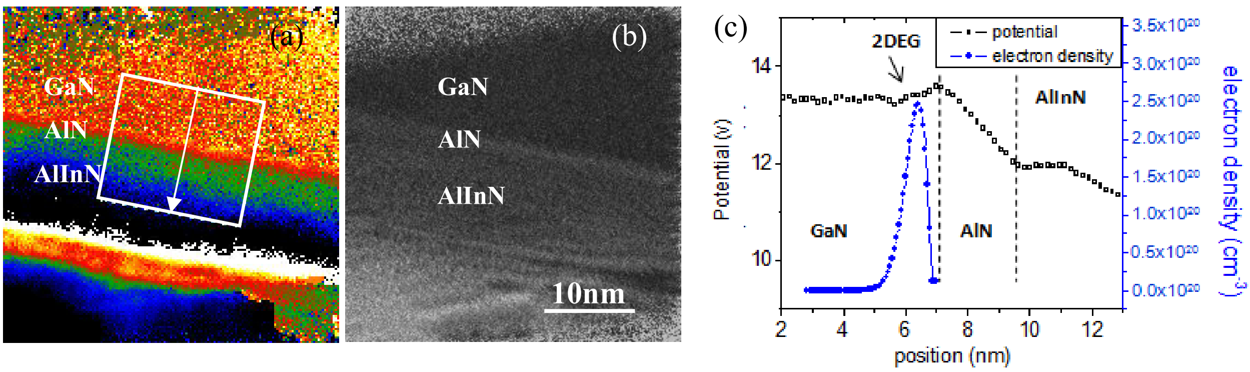

Fig. 3. (a) Phase, and (b) amplitude, images from reconstructed hologram of the HEMT structure. (c) Potential profile (open squares) and electron distribution (filled circles) across the AlInN/AlN/GaN interface.